Epidemiology and Prevention

Adverse Childhood Experiences and Blood Pressure Trajectories From Childhood to Young Adulthood

The Georgia Stress and Heart Study

Shaoyong Su, PhD; Xiaoling Wang, MD, PhD; Jennifer S. Pollock, PhD; Frank A. Treiber, PhD; Xiaojing Xu, MD, PhD; Harold Snieder, PhD; W. Vaughn McCall, MD, MS; Michael Stefanek, PhD; Gregory A. Harshfield, PhD

Background—The purposes of this study were to assess the long-term effect of adverse childhood experiences (ACEs) on blood pressure (BP) trajectories from childhood to young adulthood and to examine whether this relation is explained by childhood socioeconomic status (SES) or risk behaviors that are associated with ACEs.

Methods and Results—Systolic and diastolic BPs were measured up to 16 times (13 times on average) over a 23-year period in 213 African Americans and 181 European Americans 5 to 38 years of age. Retrospective data on traumatic experiences before 18 years of age were collected, including abuse, neglect, and household dysfunction. Individual growth curve modeling within a multilevel framework was used to examine the relation between exposure to ACEs and BP development. No main effect of ACEs on average BP levels was found. However, a significant interaction of ACE score with age \( P = 0.033 \) was observed (systolic BP, \( P = 0.017 \)). Subjects who experienced multiple traumatic events during childhood showed a faster rise in BP levels after 30 years of age than those without ACEs. As expected, a graded association of ACEs with childhood socioeconomic status and negative health behaviors was observed (\( P < 0.001 \)). The ACE–systolic BP relation was not explained by these factors, whereas the ACE–diastolic BP relation was partially mediated by illicit drug use.

Conclusion—In this novel longitudinal study, we observed that participants who were exposed to multiple ACEs displayed a greater increase in BP levels in young adulthood compared with their counterparts without ACEs. (Circulation. 2015;131:1674-1681. DOI: 10.1161/CIRCULATIONAHA.114.013104.)

Key Words: blood pressure ■ ethnic groups ■ life stress ■ longitudinal studies ■ youth

Essential hypertension is a major public health and medical challenge in the United States, with one third of US adults having high blood pressure (BP) and only about half of those having it under control. Elevated BP has been associated with increased risk of coronary heart disease and stroke, which are leading causes of death and disability in the United States.

E Editorial see p 1645
Clinical Perspective on p 1681

Previous studies, including ours, have demonstrated that levels of BP track from childhood into adulthood. As a critical developmental phase during which BP levels are programmed, environmental exposures in early life may have a long-term effect on adult BP levels. In fact, growing evidence suggests that traumatic experiences in childhood may contribute to health decline in adult life, including elevated BP levels. For example, studies in Finland have found that children who were separated from their parents during World War II showed markedly higher systolic (SBP) and diastolic (DBP) values in late adult life compared with the non-separated subjects. Socioeconomic adversity in childhood has also been suggested to be an important determinant of increased BP levels in adulthood. However, exposure to low childhood socioeconomic status (SES) is only 1 marker of early life stress and may not fully represent the psychosocial stress during childhood. Recently, childhood adversity, characterized by abuse, neglect, and household dysfunction, has been receiving increased attention as an important risk factor for cardiovascular diseases. A national study in nurses has found an association between childhood maltreatment and self-reported hypertension in middle-aged women. However, prospective studies on the association between adverse childhood experiences (ACEs) and BP development are scarce.

Received September 2, 2014; accepted February 13, 2015.
From Georgia Prevention Institute, Medical College of Georgia (S.S., X.W., X.X., G.A.H.), Department of Psychiatry and Health Behavior (W.V.M.), and Department of Psychological Sciences, College of Science and Mathematics (M.S.), Georgia Regents University, Augusta; Cardio-Renal Physiology & Medicine, Division of Nephrology, Department of Medicine, University of Alabama at Birmingham (J.S.P.); Technology Applications Center for Healthful Lifestyles, Colleges of Nursing and Medicine, Medical University of South Carolina, Charleston (F.A.T.); and Department of Epidemiology, University of Groningen, University Medical Center Groningen, The Netherlands (H.S.).

The online-only Data Supplement is available with this article at http://circ.ahajournals.org/lookup/suppl/doi:10.1161/CIRCULATIONAHA.114.013104/-/DC1.
Correspondence to Shaoyong Su, PhD, Georgia Prevention Institute, Medical College of Georgia, Georgia Regents University, 1120 15th St, HS 1721, Augusta, GA 30912. E-mail ssu@gru.edu
© 2015 American Heart Association, Inc.
Circulation is available at http://circ.ahajournals.org

DOI: 10.1161/CIRCULATIONAHA.114.013104
Given the deleterious effects of ACEs on public health and the increased risk of adult hypertension among victims exposed to ACEs, the present study investigated the long-term effect of ACEs on BP trajectories from childhood to young adulthood. In addition, there is evidence indicating that traumatic and stressful events in childhood increase the likelihood of myriad risk behaviors in adolescents and young adults from such as smoking, substance abuse, and physical inactivity, which are also risk factors for high BP. Therefore, we further examined whether the ACE effects on BP development could be explained by childhood SES and negative health behaviors. Moreover, the effect of ACEs on BP development may vary by ethnicity and sex. Adversities in childhood may matter more for minority ethnic groups (e.g., African-Americans [AAs]) or women’s health. For example, a recent study found that higher parental education levels predicted attenuated BP trajectories in women but not in men. However, the moderating effect of ethnicity and sex on the relationship between ACEs and BP development has not been explored. Because the present longitudinal cohort consisted of roughly equal number of AAs and European Americans (EAs), as well as of males and females, it afforded an opportunity to examine whether the ACE-BP relationship was moderated by ethnicity or sex.

Methods

Subjects

The participants were from the Georgia Stress and Heart (GSH) study, an ongoing longitudinal study evaluating the development of cardiovascular risk factors in youth and young adults. The data encompass a 23-year period (1989–2012) in which 16 assessments were conducted. Recruitment and evaluation of participants have been described in detail elsewhere. Briefly, subjects were recruited by use of family health history questionnaires obtained from a county-wide (Richmond County, Georgia) public school screening of children in grades kindergarten through 8 whose families were interested in health research. All subjects and their parents spoke English as their primary language, and all subjects were born in the United States. Participants were classified as AAs if both parents reported being of African heritage and they considered themselves and their child to be AA, black, or Afro-American. Participants were classified as EAs if both parents reported that they were of European ancestry and they considered themselves and their child to be EA, white, or Caucasian and not of Hispanic, Native American, or Asian descent. On the baseline evaluation, participants who met the following criteria were recruited: age of 5 to 16 years in 1989, AA or EA, normotensive for age and sex on the basis of BP screening, and free of chronic disease on the basis of parental reports of the child’s medical history. Evaluations were conducted annually from 1989 to 2000 (visits 1–10), every 1.5 years from 2002 to 2006 (visits 11–14), and every 2 years from 2008 to 2012 (visits 15 and 16). At visit 15, all subjects were ≥19 years of age, and their traumatic experiences before 18 years of age were assessed by use of the ACE questionnaire. Of the 409 subjects recruited at this visit, 394 answered this questionnaire (54% AAs and 53% female participants). There were no significant differences between those subjects who were excluded (n=15) and those who remained (n=394) in the study with respect to demographic distributions, including age, ethnicity, and sex. As shown in Table I in the online-only Data Supplement, all of the 394 subjects had at least 4 visits, and 96% of them (n=381) had ≥8 evaluations, which makes this data set very informative for the study of early life stress and BP development over time. In total, the 394 subjects yielded 5017 SBP and DBP measurements (Table I in the online-only Data Supplement). The Institutional Review Board at the Medical College of Georgia gave approval for the study. Informed consent was provided by all subjects or by parents if subjects were <18 years old. The fact that 78 of the total 394 participants were siblings may have affected the significance of observed effects; when siblings were excluded from the analyses, however, the results were virtually unchanged, so results for the entire sample are reported here.

Procedure and Measurements

On each laboratory visit, the participant was escorted to a quiet, temperature-controlled room where anthropometric and cardiovascular evaluations were conducted with the use of identical protocols by well-trained research staff. The subject’s height and weight were measured with a Healthometer medical scale that was calibrated daily. Body mass index (BMI) was calculated as a measure of general adiposity. The participant was then instrumented for the recording of BP by Dinamap (model 1864 SX). After attachment of an appropriately sized BP cuff to the right arm, the subject was placed in a supine position on a medical table with the head propped on a pillow and then given instructions to relax as completely as possible for 15 minutes. BP measurements were taken from the Dinamap at the end of the 11th, 13th, and 15th minutes. As recommended by the National Health and Nutrition Examination Survey procedures for BP measurement, the average of the last 2 readings was used to represent resting SBP and DBP.

Assessment of ACEs

The assessment of participants’ exposure to ACEs covered the first 18 years of their lives. We adapted the questions used in the ACE study. This questionnaire consists of 28 items divided into 3 categories and 10 subscales, including childhood abuse (emotional, physical, and sexual), neglect (emotional and physical), and growing up with household dysfunction (substance abuse, mental illness, domestic violence, criminal household member, and parental marital discord). The definition of ACEs has been described in the Table II in the online-only Data Supplement. As in previous ACE studies, the ACE score (the number of 10 ACE subscales reported) was used to assess the cumulative effect of multiple ACEs by classifying respondents into 4 groups: no (0 ACEs; n=122; coded 0), low (1–2 ACEs; n=149; coded 1), moderate (3 ACEs; n=49; coded 2), and severe (24 ACEs; n=74; coded as 3) exposure (Figure 1).

Childhood SES

Childhood SES was represented by the Hollingshead Four Factor Social Status Index on the basis of parental education levels and occupations. The value measured at the midpoint of the study was taken as representative for the whole study period. The Hollingshead scores ranged from 14 to 66, with higher scores representing greater childhood SES. To illustrate the BP trajectories according to childhood SES, the Hollingshead scores were divided into tertiles, indicating high (coded 0), medium (coded 1), and low (coded 2) levels of childhood SES. We further calculated a composite score of exposure to ACEs (0–3) and childhood SES (0–2) by summarizing these 2 scores, which ranges from 0 (ie, no ACE exposure and high childhood SES) to 5 (ie, severe exposure to ACEs and low childhood SES).

Negative Health Behaviors

Physical activity (PA) was assessed by the self-reported number of days per week, inside or outside of school, during which PA that was sufficient to “work up a sweat” was performed. The average of PA days across all the visits was used to represent the participant’s regular PA. This measure has been validated previously with more comprehensive self-report measures of sedentary behavior. To illustrate the PA levels on BP trajectories, the PA levels were defined as high (sufficient PA for 5–7 d/wk; coded 0), medium (sufficient PA for 2–4 d/wk; coded 1), and low (sufficient PA for 0–1 d/wk; coded 2). In the present study, ≥25% of subjects had low PA and 11% had high PA. At each visit, the participant’s smoking status was assessed by the self-reported number of days smoked during the past 30 days and the number of cigarettes smoked per day. Subjects who smoked ≥21 cigarettes in the past 30 days at any visit were considered smokers. Thirty-nine percent (n=155) of participants were current or previous smokers. In addition, the participants...
we tested whether interactions of BMI with age, ethnicity, and sex affected the growth curve. All variables that had significant effects on BP development in the previous models were entered simultaneously as a full model. In the final step, ACE score was added to the model as a categorical variable, followed by the interactions of variables with age, age^2, and age^3 and with ethnicity and sex to test whether BP grows differently by individual exposure to ACEs.

A likelihood ratio test was used to determine the significance of the fixed and random effects added to the model in each of the analysis steps. This test yields the deviance of the model, which is defined as −2×log likelihood. The deviance difference (between 2 models) is asymptotically χ^2 distributed, with the number of degrees of freedom equal to the difference in number of estimated parameters between the 2 models. To judge the significance of parameters in the full model, each parameter was removed from the model, and a likelihood ratio test with 1 df was used to examine whether its effect was significant in this full model. Multilevel modeling was performed with the program MLwiN.27

Categorized childhood SES (high, 0; medium, 1; low, 2), PA levels (high, 0; medium, 1; low, 2), smoking (no, 0; yes, 1), and use of illicit drugs (no, 0; yes, 1) and their interactions with age, age^2, and age^3 were further added to the BP growth curve models to test whether they contributed to BP development and whether the ACE-BP relation was independent of these factors. The interactions of risk behaviors and ACEs were also examined. Furthermore, we examined the composite effect of exposure to ACEs and childhood SES on BP trajectories by using the composite scores as calculated above.

**Results**

Descriptive characteristics by ethnicity and sex at participants’ first evaluation are shown in Table 1. Compared with EA youth, AA youth had significantly higher BMI, SBP, and DBP and lower childhood SES (P<0.001). EA youth performed more exercise than AA youth (P=0.001). However, more EA youth were smoking (P<0.001) and using illicit drugs (P=0.055). Female participants had higher BMI and DBP but lower SBP than male participants. Compared with male participants, female participants performed less exercise and had lower rates of smoking and use of illicit drugs (P<0.001). Of note, participants were still relatively young at their last evaluations, with a mean age of 30 years (age range, 20–38 years).

**Prevalence of ACEs**

The prevalence of each individual ACE subscale is shown in Figure 1, with the lowest prevalence being physical neglect.
Table 1. Descriptive Characteristics of 394 Participants by Ethnicity and Sex at the First Evaluation

<table>
<thead>
<tr>
<th></th>
<th>EA</th>
<th></th>
<th>EA</th>
<th></th>
<th>P Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>97</td>
<td>84</td>
<td>89</td>
<td>124</td>
<td>0.425</td>
</tr>
<tr>
<td>Age, y†</td>
<td>12.1 (3.87)</td>
<td>11.8 (3.70)</td>
<td>12.4 (3.68)</td>
<td>12.1 (3.25)</td>
<td>0.572</td>
</tr>
<tr>
<td>BMI, kg/m²†</td>
<td>19.7 (4.30)</td>
<td>20.9 (5.80)</td>
<td>22.5 (6.50)</td>
<td>23.3 (7.97)</td>
<td>0.006</td>
</tr>
<tr>
<td>SBP, mmHg†</td>
<td>106.4 (9.61)</td>
<td>104.1 (7.86)</td>
<td>111.1 (12.59)</td>
<td>107.3 (9.91)</td>
<td>0.013</td>
</tr>
<tr>
<td>DBP, mmHg†</td>
<td>56.4 (5.44)</td>
<td>57.7 (6.09)</td>
<td>59.9 (6.57)</td>
<td>60.5 (6.76)</td>
<td>0.036</td>
</tr>
<tr>
<td>PA, d/wk</td>
<td>3.56 (1.26)</td>
<td>2.71 (1.32)</td>
<td>3.36 (1.39)</td>
<td>2.18 (1.40)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Smoking, n (%)</td>
<td>59 (60.8)</td>
<td>31 (36.9)</td>
<td>40 (44.9)</td>
<td>25 (20.2)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Use of illicit drugs, n (%)</td>
<td>43 (44.3)</td>
<td>22 (26.2)</td>
<td>34 (38.2)</td>
<td>23 (18.6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ACEs, n (%)</td>
<td>0</td>
<td>35 (36.08)</td>
<td>29 (34.52)</td>
<td>22 (24.72)</td>
<td>36 (29.03)</td>
</tr>
<tr>
<td></td>
<td>1–2</td>
<td>37 (38.14)</td>
<td>34 (40.48)</td>
<td>30 (33.71)</td>
<td>48 (38.71)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>9 (9.28)</td>
<td>9 (10.71)</td>
<td>12 (13.48)</td>
<td>19 (15.32)</td>
</tr>
<tr>
<td></td>
<td>≥4</td>
<td>16 (16.49)</td>
<td>12 (14.29)</td>
<td>25 (28.09)</td>
<td>21 (16.94)</td>
</tr>
</tbody>
</table>

AA indicates African American; ACE, adverse childhood experience; BMI, body mass index; DBP, diastolic blood pressure; EA, European American; PA, physical activity; and SBP, systolic blood pressure.
*Adjusted for age, ethnicity, and sex.
†Mean value (SD) at the first evaluation.
‡Mean value (SD) at the midpoint of the study.

(9.4%) and the highest prevalence being parental marital discord (38.2%). Overall, 69% of respondents reported at least 1 exposure to ACEs, with mild (1–2 ACEs), moderate (3 ACEs), and severe (≥4 ACEs) exposure to ACEs representing 37.9%, 12.5%, and 18.8%, respectively (Figure 1). As shown in Table 1, the prevalence of ACE exposure was similar between male (69.4%) and female (68.8%) participants but was slightly higher in AAs (72.8%) than in EAs (64.6%). AA male participants had the highest prevalence of severe exposure to ACEs (ACE score ≥4, 28.1%) compared with the other 3 groups.

ACEs, Childhood SES, and Negative Health Behaviors
A graded association of the ACE scores with childhood SES and negative health behaviors was observed, except for physical inactivity (Table 2). Subjects who were exposed to more ACEs showed significantly lower childhood SES. The prevalence of smoking and using illicit drugs was increased 2- and 2.5-fold among persons with ≥4 ACEs compared with those with 0 ACEs. Adjustment for age (at the 15th visit when ACEs were assessed), ethnicity, and sex did not change the results.

ACEs and SBP/DBP Growth Curves
Figures 2 and 3 depict the results for the analyses of ACE effects on the development of SBP and DBP based on the most parsimonious full model shown in the footnote. No main effect of ACEs on BP average levels was found. However, a significant interaction of ACE score with age3 was observed (SBP: \( \beta = 0.0004617, SE = 0.0002155, P = 0.033 \); DBP: \( \beta = 0.0003864, SE = 0.0001609, P = 0.017 \)). Young adults who experienced multiple traumatic events during childhood showed a faster increase in BP levels than those with no ACEs. Notably, these differences were observable after the age of 30 years. On the basis of the prediction model, at the age of 38 years, subjects with ≥4 ACEs had average SBP and DBP levels 9.3 and 7.6 mm Hg higher, respectively, than those with 0 ACEs after controlling for ethnicity, sex, and BMI. No significant interactions of ACE score with ethnicity and sex were found (data not shown), indicating that...
the exposure to ACEs had similar effects on BP development of EAs and AAs, as well as of male and female participants.

Because of the inexact knowledge of when the traumatic events occurred before the age of 18 years, there may have been a mismatch between ACE exposure and BP measurement during childhood. Therefore, we repeated all analyses among subjects at ≥18 years, which yielded 2830 SBP and DBP measurements. As shown in Figures 4 and 5, similar ACE effects were found on SBP and DBP growth curves (ie, significant interaction with age2 in this case), indicating that subjects who were exposed to ACEs had a higher increase in BP in young adulthood compared to those with no ACEs.

Effects of Risk Behaviors

In the SBP growth model, no significant main effects or interactions with age were found for behavioral risk factors, including physical inactivity, smoking, and use of illicit drugs. After these factors were controlled for, the association between ACEs and SBP trajectories was virtually unchanged. For DBP, a significant interaction of illicit drug use with age was observed (β=0.1341; SE=0.0443; P=0.002), suggesting a greater increase in DBP among subjects who used illicit drugs (Figure I in the online-only Data Supplement). After adjustment for this factor and its interaction with age, the association between ACEs and DBP growth was attenuated but still significant (ACEs×age2: β=0.0003179, SE=0.0001618, P=0.04). Furthermore, there were no significant interaction effects between risk behaviors and ACEs on BP development.

ACEs, Childhood SES, and BP Trajectories

To distinguish the effects of ACE exposure and childhood socioeconomic disadvantage, we further examined the relationship between childhood SES and BP trajectories over time. Similar to the effect of ACEs on SBP, a significant interaction of childhood SES with age was observed for SBP (β=0.00111; SE=0.000481; P=0.02; Figure II in the online-only Data Supplement) but not for DBP. However, after ACE score and childhood SES were added simultaneously into the model, both effects were attenuated and not significant (ACEs×age3: β=0.0003304, SE=0.0002272, P=0.14; childhood SES×age3: β=0.0005181, SE=0.0003015, P=0.08), which might be attributable to the collinearity between these 2 factors (Spearman ρ=0.3; P<0.001). We further examined the composite score of exposure to ACEs and childhood SES and found a significant interaction of this score with age on SBP (β=0.0004057; SE=0.00015; P=0.006) and on DBP (β=0.0002299; SE=0.0001126; P=0.03). Given the fact that 35% of the participants with ≥4 ACEs came from medium- or high-SES families and one third had no history of ACEs but...
had low SES, our results suggested that these 2 factors were linked but were not redundant.

**Discussion**

Taking advantage of a longitudinal cohort composed of EA and AA boys and girls who were followed up for 23 years (1989–2012) with up to 16 assessments (13 on average) of BP, for the first time, we found a significant association between the number of ACEs and BP trajectories from childhood to young adulthood. Participants who experienced multiple traumatic events before 18 years of age showed greater increases in BP levels in young adulthood compared with those who were not exposed to ACEs. The enduring consequences of ACEs were not fully explained by established concurrent risk factors such as childhood SES, smoking, and use of illicit drugs. In addition, no significant interactions of ACEs with ethnicity or sex on BP development were observed, suggesting a similar effect of ACEs for BP across different population groups.

**Major Features**

One unique and important feature of the present study is that it involved BP measured every 1 or 2 years over a 23-year period from childhood to young adulthood. The analytic strategy we used, that is, the multilevel growth curve modeling, enabled us to investigate the influence of early life stress in the development of BP over time. Previous studies have suggested that psychosocial factors and stress in early life contribute to hypertension in adults, whereas the history of hypertension was self-reported. The present study confirmed and extended previous findings. This study demonstrated that young adults who were exposed to ACEs had a more rapid rise in BP levels in the third decade of life, suggesting that ACE exposure results in a higher risk for developing hypertension, most likely at an earlier age, than their counterparts without a history of ACEs. Moreover, consistent with previous findings, children exposed to a greater number of adverse experiences have a greater increase in both SBP and DBP in young adulthood, suggesting a cumulative effect of childhood adversities on BP development over time.

The second feature of the present study is that we evaluated participants’ early family environments by including the assessments of both childhood SES and traumatic experiences with respect to abuse, neglect, and household dysfunction. Our results indicate that groups of children exposed to adverse events and low SES do not necessarily overlap. For example, 50% of our participants with a history of childhood abuse and 40% of children who reported being neglected came from medium- or high-SES families, which agrees with previous findings. Consequently, exposure to ACEs may exert effects on BP trajectories that are independent of childhood SES. ACE exposures contributed to the development of both SBP and DBP, whereas childhood SES was associated only with SBP, not DBP, growth. Relieving childhood poverty alone may be insufficient to eliminate the BP-related health problems associated with ACEs.

The third unique feature of the present study cohort is that it incorporated roughly equal numbers of EAs and AAs and of male and female participants. In line with previous research with this cohort, we found that significant differences in average BP levels emerged by ethnicity and sex from early adolescence onward, with AAs having higher SBP and DBP than EAs, and male participants having higher SBP but lower DBP than female participants. Although AAs had a slightly higher prevalence of exposure to ACEs than EAs, there was no significant difference of ACEs on BP trajectories between the 2 ethnic groups. A recent study suggested that sex might modify the association between childhood SES and BP trajectories. Increasing parental education was associated with flatter SBP and DBP growth among women but not men. In the present study, however, no significant interaction was found between sex and ACEs on BP development, suggesting that exposure to ACEs may have similar effects on BP growth from childhood to young adulthood in male and female participants.

**Mechanisms Linking ACEs to Elevated BP**

**Unhealthy Behaviors**

Multiple ACEs indicate a harsh and stressful environment, and early exposure to ACEs can lead to adoption of risky lifestyle behaviors such as smoking and substance abuse. Some studies, but not all, have suggested that the relation of ACEs to poor health outcomes was mediated at least partially by risk behaviors. In the present study, although a graded association of ACE score with unhealthy behaviors was observed, the ACE-BP relation was mostly independent of these factors. Only the use of illicit drugs had a significant influence on BP trajectories over time and partially mediated the association between ACEs and DBP growth. Of note, participants in the present study were still relatively young at the end of this study; therefore, the influences of risk behaviors on BP may not be so significant. As these subjects continue to age, risk behaviors may play an increasingly important role in middle or late adulthood.

**Physiological Pathways**

Given the fact that multiple systems, for example, nervous, endocrine, and immune systems, are not fully developed at birth and...
show profound changes during childhood, adversities in early life may shape the experience-dependent maturation of stress-related pathways underlying these systems, leading to long-lasting altered stress responsivity in adulthood. Indeed, traumatic experiences in childhood have been associated with hyperactivity of the hypothalamic-pituitary-adrenal axis and sympathetic nervous system, as well as elevated inflammation in adults. Alterations in these systems may mediate the effect of early life stress on the dysregulation of BP. In addition, BMI is a major determinant of BP development. Previous reports showed that children with a history of physical abuse were more likely to have higher BMI as adults than those with no exposure to abuse. In the present study, adjustment for BMI did not change the association between ACEs and BP trajectories, suggesting that adverse experiences before the age of 18 years may affect BP development in young adults through a mechanism independent of BMI. Most recently, our studies in rats and humans suggested that exposure to early life stress may induce elevated plasma endothelin-1 levels, indicating that the endothelin-1 pathway may underlie the link between early trauma and later development of BP.

**Limitations**

Our study has several limitations. First, similar to previous large cohort studies, the individual’s experiences of childhood adversity were collected through retrospective self-report. Because of the sensitive nature of questions about ACEs and affective problems, the responses probably represent an underreporting of their actual occurrence. However, given the established relationship between ACE and the risk for cardiovascular disease development, the underreporting of the adversities, if it exists, should have weakened the associations we found here, not exaggerated them. Second, we assessed participants’ adverse experiences before the age of 18 years but without exact knowledge of the time frame when these adversities occurred. There may be a mismatch between ACE exposure and BP measurement during childhood. However, by limiting to subjects ≥18 years of age, repeated analyses revealed similar relations of ACE scores with BP trajectories over time, suggesting that traumatic experiences in early life may contribute to the increase of BP in young adulthood. Third, subjects with hypertension and other chronic diseases were excluded from the baseline recruitment. This may constrain the variance of the ACE exposure and induce some selection bias because children who experience the greatest degree of adversity early in life may also be unhealthier. Given that this subpopulation may have the highest risk of developing cardiovascular disease in adulthood, exclusion of these subjects would be predicted to weaken, not exaggerate, the association between ACE exposure and BP development. Fourth, the effects of emotional factors such as depression and anxiety were not evaluated in the present model. Previous studies have suggested that early life stress may exert effects on adult health outcomes, in part by compromising emotional functioning across the life span. The role of emotional factors in the relation of ACE and BP trajectories warrants further investigation in the future as this longitudinal cohort continues. Finally, the sample size of the present study was relatively small. Although we assessed BP in up to 16 visits (13 visits on average) and had sufficient power to detect the effect of ACEs on BP growth, we may not have had enough power to detect the significant interactions of ACEs with ethnicity and sex on BP development. In addition, we found that the effects of ACEs and childhood SES on BP trajectories were not independent of each other. Although this might be attributable to the high correlation between these 2 factors, we may also have had insufficient power to distinguish their effects. Larger sample size and longer follow-up are warranted in future research.

**Conclusions**

The present study provides a unique opportunity to assess the relationship between childhood adversities and the longitudinal BP trajectories from childhood to young adulthood. The data are consistent with previous research on the role of early life stress in the pathogenesis of hypertension and further demonstrate that young adults who experienced multiple traumatic events in childhood already display elevated BP levels compared with their counterparts without a history of ACEs. The enduring consequences of ACEs were similar in EAs and AAs, as well as in male and female participants, and were not fully explained by childhood SES and unhealthy behaviors. Of note, participants in the present cohort were still relatively young at the end of this study. Experiencing childhood adversity may contribute to elevations in hypertensive risk earlier in the life course than previously thought or expected. Identification and early intervention in young adults with experiences of childhood adversity may provide an important avenue for lessening the burden of cardiovascular disease in later adult life.

**Acknowledgments**

We acknowledge the continued cooperation and participation of the members of the Georgia Stress and Heart Study and their families and thank the tireless staff at the Georgia Prevention Institute.

**Sources of Funding**

This research was supported in part by the National Institutes of Health Program Project Grant on Stress-Related Mechanisms of Hypertensive Risk (P01 HL69999 to Drs Harshfield, Treiber, Snieder, and Pollock). Dr Su is funded by the American Heart Association (09SDG2140117) and the National Institutes of Health (HL106333-01A1).

**Disclosures**

None.

**References**


22. Hollingshead A. Four Factor Index of Social Status. New Haven, CT: Department of Sociology, Yale University; 1981.


**CLINICAL PERSPECTIVE**

Childhood adversity, characterized by abuse, neglect, and household dysfunction, is receiving increased attention as an important risk factor for cardiovascular disease, including hypertension. In the present novel longitudinal study, we demonstrated a significant association between adverse childhood experiences and blood pressure trajectories over time. Participants who experienced multiple traumatic events in childhood already display elevated blood pressure levels in young adulthood compared with their counterparts with no adverse childhood experiences. As they continue to age, these subjects may have a higher risk of developing hypertension and coronary heart disease in middle or late adulthood. Our findings are especially relevant to the practices of medicine and public health. Screening for or learning about a history of adverse childhood experiences in youth and young adults will aid the physician’s understanding of the patient’s circumstances and will help the physician adapt current strategies to promote healthy physical and psychological outcomes. Early intervention in young adults with experiences of childhood adversity may mobilize resilience and recovery and, therefore, provide an important avenue for lessening the burden of cardiovascular disease in later adult life.
Adverse Childhood Experiences and Blood Pressure Trajectories From Childhood to Young Adulthood: The Georgia Stress and Heart Study
Shaoyong Su, Xiaoling Wang, Jennifer S. Pollock, Frank A. Treiber, Xiaojing Xu, Harold Snieder, W. Vaughn McCall, Michael Stefanek and Gregory A. Harshfield

Circulation. 2015;131:1674-1681; originally published online April 9, 2015; doi: 10.1161/CIRCULATIONAHA.114.013104

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/131/19/1674

Data Supplement (unedited) at:
http://circ.ahajournals.org/content/suppl/2015/04/09/CIRCULATIONAHA.114.013104.DC1

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/
**Supplemental Table 1.** The number and percentage of all the 394 subjects who had blood pressure measured multiple times over a 23-year period

<table>
<thead>
<tr>
<th>Number of BP assessments</th>
<th>Number of subjects</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>394</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>394</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>394</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>394</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>393</td>
<td>99.75</td>
</tr>
<tr>
<td>6</td>
<td>392</td>
<td>99.49</td>
</tr>
<tr>
<td>7</td>
<td>390</td>
<td>98.98</td>
</tr>
<tr>
<td>8</td>
<td>381</td>
<td>96.70</td>
</tr>
<tr>
<td>9</td>
<td>362</td>
<td>91.88</td>
</tr>
<tr>
<td>10</td>
<td>326</td>
<td>82.74</td>
</tr>
<tr>
<td>11</td>
<td>307</td>
<td>77.92</td>
</tr>
<tr>
<td>12</td>
<td>272</td>
<td>69.04</td>
</tr>
<tr>
<td>13</td>
<td>211</td>
<td>53.55</td>
</tr>
<tr>
<td>14</td>
<td>189</td>
<td>47.97</td>
</tr>
<tr>
<td>15</td>
<td>143</td>
<td>36.29</td>
</tr>
<tr>
<td>16</td>
<td>75</td>
<td>19.04</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5,017</strong></td>
<td></td>
</tr>
</tbody>
</table>
### Supplemental Table 2. Definition and prevalence of each category of ACE and ACE Scores

<table>
<thead>
<tr>
<th>Category</th>
<th>Exposed to ACEs</th>
<th>Prevalence (%) (N=394)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abuse</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Emotional</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Did a parent or other adult in the household, never, sometimes, often or very often <strong>Respond “often” or “very often” to either question</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Swear at you, insult you, or put you down?</td>
<td>12.76</td>
<td></td>
</tr>
<tr>
<td>(2) Act in a way that made you afraid that you might be physically hurt?</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Physical</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Did a parent or other adult in the household, never, sometimes, often or very often <strong>Respond “often” or “very often” to the first question or “sometimes, often, or very often” to the second</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Push, grab, slap, or throw something at you?</td>
<td>17.60</td>
<td></td>
</tr>
<tr>
<td>(2) Hit you so hard that you had marks or were injured?</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Sexual</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Did an adult or person at least 5 years older ever <strong>Respond affirmatively to any of these questions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Touch or fondle you? (2) Have you touch their body in a sexual way? (3) Attempt, or (4) Actually have oral, anal, or vaginal intercourse with you?</td>
<td>16.33</td>
<td></td>
</tr>
<tr>
<td><strong>Neglect</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Emotional</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Following statement is never, sometimes, often, very often true. Questions were reverse-scored and summed on a Likert scale. Persons with a score of 15 or higher (moderate or extreme) were considered to have experienced emotional neglect.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) There was someone in my family who helped me feel important or special. (2) I felt loved. (3) People in my family looked out for each other. (4) People in my family felt close to each other. (5) My family was a source of strength and support.</td>
<td>11.42</td>
<td></td>
</tr>
<tr>
<td><em>Physical</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Following statement is never, sometimes, often, very often true. Questions were scored and summed on a Likert scale, with questions 2 and 5 reverse-scored. Persons with a score of 10 or higher (moderate or extreme) were considered to have experienced physical neglect.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) I didn't have enough to eat. (2) I knew there was someone there to take care of and protect me. (3) My parents were too drunk/high to take care of me. (4) I had to wear dirty clothes. (5) There was someone to take me to the doctor if I needed it.</td>
<td>9.39</td>
<td></td>
</tr>
<tr>
<td><strong>Household dysfunction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Substance abuse</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you lived with anyone who <strong>Respond affirmatively to either</strong></td>
<td>26.90</td>
<td></td>
</tr>
</tbody>
</table>
(1) Was a problem drinker or alcoholic?
(2) Used street drugs?

**Mental illness**
Have you lived with anyone who
(1) Was depressed or mentally ill?
(2) Attempted suicide?

**Domestic violence**
Was your mother (or stepmother), never, sometimes, often or very often
(1) pushed, grabbed, slapped, or had something thrown at her?
(2) kicked, bitten, hit with a fist, or hit with something hard?
(3) repeatedly hit over at least a few minutes?
(4) threatened with or hurt by a knife or gun?

**Criminal household member**
Did a household member go to prison?

**Parental marital discord**
Were your parents ever separated or divorced?

ACE Score (the number of subscales of ACEs reported)

<table>
<thead>
<tr>
<th>Score</th>
<th>Frequency</th>
<th>ACE Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (n=122)</td>
<td>30.96</td>
<td></td>
</tr>
<tr>
<td>1-2 (n=149)</td>
<td>37.82</td>
<td></td>
</tr>
<tr>
<td>3 (n=49)</td>
<td>12.44</td>
<td></td>
</tr>
<tr>
<td>4+ (n=74)</td>
<td>18.78</td>
<td></td>
</tr>
</tbody>
</table>
Supplemental Figure 1. The predicted diastolic blood pressure with age by use of illicit drugs.
Supplemental Figure 2. The predicted systolic blood pressure with age by the childhood SES levels. Growth curves (from bottom to top at the age of 38 years old) represent high, medium and low levels of childhood SES.